

Final Project Report
NAG3-1832
Microgravity Research Division

PIs Last Name	Dhir
First Name	Vijay
Middle Initial	K.
Prefix	Dr.
Suffix	
Affiliation	University of California, Los Angeles

Phone: 310 825-8507	Fax: 310 206-4830
Email: vdhir@seas.ucla.edu	

Address:

Mechanical and Aerospace Engineering Department
48-121 Engr. IV, Box 951597
University of California, Los Angeles
Los Angeles, CA 90095-1597

Task Research Title

Investigations of Mechanisms Associated with Nucleate Boiling under Microgravity Conditions

<i>Monitoring Center</i>	GRC		
<i>Research Type</i>	Flight	<i>Discipline</i>	Fluid Physics
<i>Initiation Date</i>	May-96	<i>Expiration Date</i>	May-00

Degree	Students	Degrees
BS	0	0
MS	1	1
PhD	4	0
Post-Docs	2	0
Totals	7	1

Co-Investigator Name	Co-Investigator Affiliation
1. Hasan, M.	NASA Glenn Research Center
2.	
3.	
4.	
5.	
6.	

Task Monitor Chao, D.
Task Monitor email

Phone 216 433-8320
David.F.Chao@grc.nasa.gov

Impact on America

Industrial Affiliates

Please list any industry research contacts you may have

Who is using the results of your research?

Have you developed any innovative technologies, and if so, what are they?

We have found that by depositing an ultra-thin porous film on the heater surface, heat transfer rate can be significantly enhanced under partial nucleate boiling conditions. We are currently trying to test the limits of enhancement. If enhancement is found to be sufficiently higher than that obtained from the available techniques, this technique will have a potential for commercialization.

Where have your recent graduate students found employment?

One M.S. student who was supported by the project has been employed by the electronics industry.

Acronyms(Please list and define any acronyms associated with your project)

Task Objective

In this work a building block type of approach is used so that a basic understanding of the processes that contribute to nucleate boiling heat fluxes under microgravity conditions can be developed. This understanding will lead to development of a mechanistic model for nucleate boiling heat transfer which could eventually be used as a design tool in space applications.

Task Description

Task 1: Fabrication of the Experimental Setup. Under this task, the test section and liquid holding and viewing chambers will be fabricated. Artificial cylinder cavities will be formed on silicon wafers. A single cavity and two or four cavities, with a prescribed spacing and size, will be formed. The desired nucleation wall superheat will be used to determine the size of the mouth of the cavities.

Task 2: Experiments. The basic experiments for flow and temperature field around single and multiple (2 or 4 separated or merged bubbles growing on downward facing or inclined surfaces) will be carried out under normal gravity conditions. The experiments will be conducted at one atmosphere pressure, but liquid subcooling will be varied from 0 to 30°C. Water and PF-5050 will be used as test liquids.

Task 3: Analytical/Numerical Models. In this task, transient temperature and flow field in vapor and liquid will be determined during growth of a single bubble. Analysis will include the evolution of the vapor-liquid interface and development of microlayer underneath the bubbles. For merged bubbles, detailed calculations of flow and temperature field will be carried out for transient shapes of vapor stems supporting a large bubble and the corresponding evaporation rate. Flow and temperature field for a bubble sliding along a heated wall will also be determined. Microgravity conditions will be simulated and a framework of a numerical tool for prediction of nucleate boiling heat fluxes under microgravity conditions will be developed.

Task 4: Experiments in a KC-135. To understand bubble growth and detachment behavior of single or large merged bubbles, boiling experiments will be conducted under low gravity (10-2 g) conditions of the aircraft. In these experiments, "designed" surfaces will be used. Visual observations and heat transfer data will be taken, but holography will not be used. The apparatus used for laboratory experiments will also be employed for experiments in the aircraft.

Task 5: Experiments in the Space Shuttle. Effort will be devoted for defining a boiling experiment to be conducted on a "designed" surface. The experiment will provide microgravity data on bubble growth and departure. These data are needed for development of a credible model for nucleate boiling heat fluxes under microgravity conditions. The heat transfer data will also be obtained and will be used to validate the models.

Task Significance

Boiling is known to be a very efficient mode of heat transfer, and as such, it is employed in component cooling and in various energy conversion systems. For space applications boiling is the heat transfer mode of choice, since for a given power rating the size of a component can be significantly reduced. Applications of boiling can be found in the areas of thermal management, fluid handling and control, power systems, on-orbit storage and supply systems for cryogenic

propellants and life support fluids, cooling of electronic packages for power systems associated with various instrumentation and control systems, and various processes associated with ISRU.

Task Progress

Experiments and numerical simulations have been performed to develop a mechanistic understanding of nucleate boiling under microgravity conditions. Experimental apparatus have been developed to conduct detailed experiments at earth normal gravity and in the low gravity environment of the KC-135 aircraft. In the experiments, silicon wafers with pre-designed microfabricated cavities etched in them are used as the test surfaces. Several micro-heaters and thermocouples are bonded on the backside of the heater. The power to the heaters is controlled so that nearly constant surface temperature exists on the heater surface. Dynamics and heat transfer associated with single and multiple bubbles have been investigated. From experiments in the KC-135, it is found that equivalent diameter of the merged vapor mass at departure is smaller than that of a single bubble. This suggests that under low gravity conditions, the lift force resulting from the liquid circulation created during bubble merger process plays an important role in lifting the bubble away from the surface. This finding is very significant for developing an understanding of vapor removal under microgravity conditions. To investigate the effect of surface wettability, two liquids – water and PF 5060 are used in the experiments.

Numerical simulations of the evolving vapor-liquid interface and the associated heat transfer and flow dynamics have been carried out. The results from the numerical simulations of single bubbles are found to be in very good agreement with the data. The numerical simulations consistent with data show that bubble diameter at departure scales as inverse square root of gravity, whereas the growth period varies inversely with the level of gravity. Recently, the two dimensional numerical simulation tool has been expanded to three dimensions, in order to understand the dynamics of merged bubbles.

The first design of pool boiling apparatus for experiments in the space station has been completed. The apparatus has partly been fabricated. After completion, shakedown tests using the new apparatus will be conducted. Software for uplink and downlink will also be developed.

Bibliography

Number of times that your work has appeared in the popular press?

Number of times that your work has appeared on a magazine cover?

Citations

1. Son, G., and Dhir, V.K., "Numerical Simulation of a Single Bubble During Partial Nucleate Boiling on a Horizontal Surface", Proc. of 11th International Heat Transfer Conference, Kyongju, Korea, 1998, Vol. 2, pp. 533-538.
2. Son, G., and Dhir, V.K., "Numerical Simulation of Film Boiling Near Critical Pressures with a Level Set Method", Journal of Heat Transfer, Vol. 120, 1998, pp. 183-192.
3. Dhir, V.K., Qiu, D.M., Ramanujapu, N., and Hasan, M.M., "Investigation of Nucleate Boiling Mechanisms Under Microgravity Conditions", Proc. of Microgravity Fluid Physics Conference, Cleveland, OH, August 12-14, 1998.
4. Qiu, D.M., and Dhir, V.K., "An Experimental Study of Heat Transfer During Sliding of Bubbles on Inclined Surfaces", Proc. 5th ASME/JSME Joint Thermal Engrg. Conf., March 15-19, 1999, San Diego, CA.
5. Ramanujapu, N., and Dhir, V.K., "Dynamics of Contact Angle During Growth and Detachment of a Vapor Bubble at a Single Nucleation Site", Proc. 5th ASME/JSME Joint Thermal Engrg. Conf., March 15-19, 1999, San Diego, CA.
6. Son, G., Dhir, V.K., and Ramanujapu, N., "Dynamics and Heat Transfer Associated with a Single Bubble During Nucleate Boiling on a Horizontal Surface", J. Heat Transfer, Vol. 121, August 1999, pp. 623-631.
7. Qiu, D.M., Dhir, V.K., Hasan, M.M., Chao, D., Neumann, E., Birchenough, A., and Withrow, J., "Single Bubble Dynamics during Nucleate Boiling under Low Gravity Conditions," Proc. Int'l. Conf. on Microgravity Fluid Physics and Heat Transfer, Sept. 19-24, 1999, Oahu, HI, Begell House Inc., NY, publ.
8. Singh, S. and Dhir, V.K., "Effect of Gravity, Wall Superheat and Liquid Subcooling on Bubble Dynamics during Nucleate Boiling," Proc. Int'l. Conf. on Microgravity Fluid Physics and Heat Transfer, Sept. 19-24, 1999, Oahu, HI, Begell House Inc., NY, publ.
9. Qiu, D., and Dhir, V.K., "Measurement of Refractive Index of PF-5060", International Journal of Experimental Thermal Fluid Science, 1999. Dhir, V.K., ed., "Microgravity Fluid Physics and Heat Transfer", Begell House, Inc., New York, NY, 2000.
10. Qiu, D.M., Dhir, V.K., Hasan, M.M., Chao, D., Neumann, E., Yee, G., Birchenough, A., and Withrow, J., "Dynamics of Bubble Growth, Departure, and Merger during Nucleate boiling under Low Gravity Conditions," 39th Aerospace Sciences Meeting and Exhibit, 10-13 January 2000, Reno, NV.
11. Qiu, D.M., Singh, S., and Dhir, V.K., "Dynamics of Bubble Growth on a Heated Surface under Low Gravity Conditions," Space Technology and Applications International Forum, 30 January - 3 February 2000, Albuquerque, NM.

12. Dhir, V.K., "On the Use of Numerical Simulations to Augment our Understanding of Boiling Heat Transfer," Kern Award Paper NTCH2000-12303, 34th National Heat Transfer Conference, 20-22 August 2000, Pittsburgh, PA.
13. Qiu, D. Dhir, V.K., Hasan, M.M., Chao, D., "Single and Multiple Bubble Dynamics during Nucleate Boiling under Low Gravity Conditions," Paper NHTC2000-12207, 34th National Heat Transfer Conference, 20-22 August 2000, Pittsburgh, PA.
14. Ramanajapu, N., Dhir, V.K., "On the Formation of Vapor Columns and Mushroom Type Bubbles during Nucleate Boiling on a Horizontal Surface," Paper NHTC2000-12208, 34th National Heat Transfer Conference, 20-22 August 2000, Pittsburgh, PA.
15. Qiu, D., and Dhir, V.K., "Experimental Study of Flow Pattern and Heat Transfer Associated with a Bubble Sliding on Inclined Surfaces", 4th Intl. Conference on Multiphase Flow, New Orleans, LA, May, 2001.